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PHASED NIF START-UP*

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NIF Start-up and Operations Enginering

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ABSTRACT

We describe a phased start-up plan for the 192-beam line National Ignition Facility, that supports a gradual transition of the present ICF program, based upon the 10 beam Nova laser system to a NIF based ICF program, with all 24 bundles being available for operation in FY04. This plan is based upon a bundle-by-bundle completion of integrated operational test procedures and hand-over to the program for experiments. The early execution of the start-up of one bundle not only provides experimental capability two years before completion of the NIF Project, but its experience will be essential to complete this transition plan in a timely and cost effective way.

## I. INTRODUCTION

The National Ignition Facility[1] (NIF) is a high-power laser facility being constructed to support the United States Stockpile Stewardship and Management Program, inertial fusion ignition physics experiments, weapons effects testing, and enable other research efforts in the area of high energy density physics and astrophysics[2,3]. The NIF laser driver consists of 192 laser beams arranged in 24 bundles. The 24 bundles are split into 48 beam quads, each of which is frequency converted from 1.05 μm to 0.351 μm and focused onto the center of a 10 meter diameter evacuated target chamber. Figure 1 shows an isometric view of the NIF facility. By the completion of the NIF Construction Project at the end of FY03, all 24 laser bundles will have been installed in the facility, and all 12 laser bundles of the first laser bay will be fully operational. Full operation of all 24 NIF laser bundles is expected by the end of FY04. In order to minimize the time between shutdown of the 10 beam Nova laser facility at LLNL and commencement of target physics experiments in the NIF, a transition plan was adopted which calls for bundle-by-bundle laser start-up and ICF Program experiments/operation of each bundle as it successfully completed its operational test requirements. In this manner Program experiment/operation can begin in FY02 following start-up testing of the first "early" laser bundle of eight beam lines and two years before Project completion.

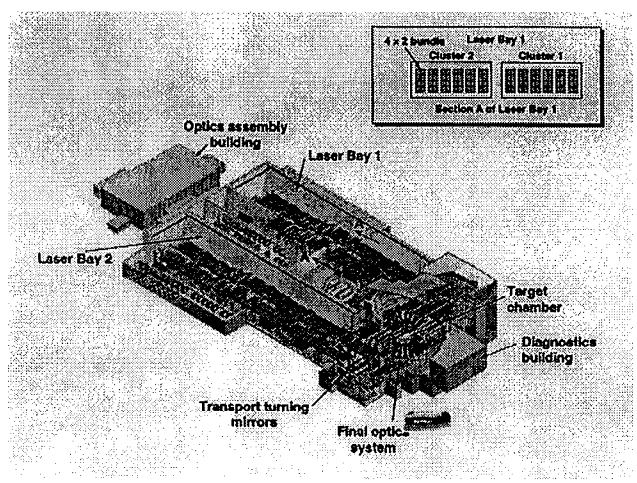


Figure 1.

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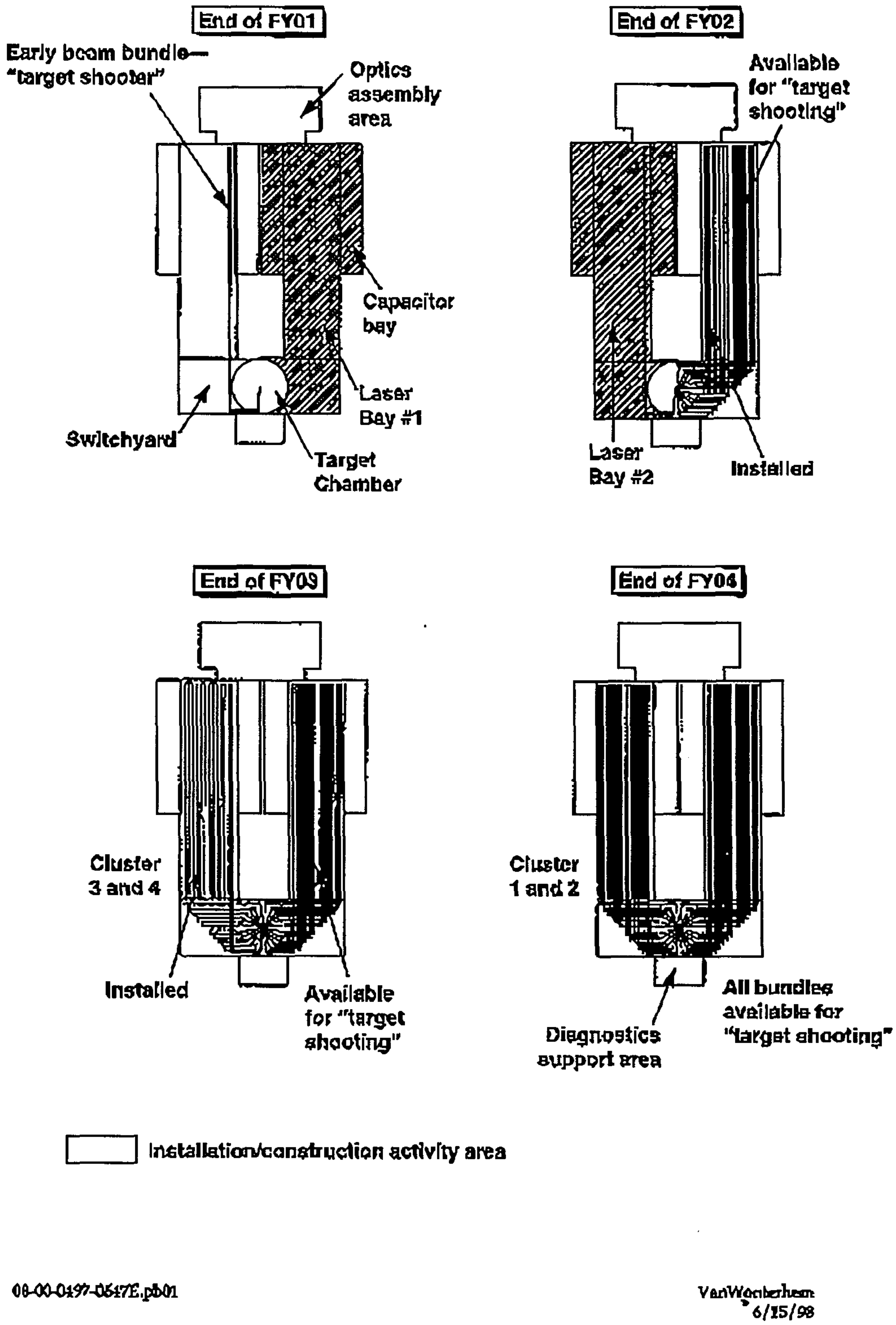
End of FY01
Early beam bundle—"target shooter"
Optics assembly area
Capacitor bay
Laser Bay #1
Switchyard
Target Chamber
End of FY02
Available for "target shooting"
Laser Bay #2
Installed
End of FY03
Cluster 3 and 4
Installed
Available for "target shooting"
End of FY04
Cluster 1 and 2
All bundles available for "target shooting"
Diagnostics support area
Installation/construction activity area
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VanWonterhem
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Figure 2.

The NIF facility[1] consists of two laser bays, each one housing 12 laser bundles, two switchyards, which contain the transport optics to direct the beams to the target chamber. In the switchyards, each bundle is split vertically into two beam quads (2x2 beam lines), half of which illuminate the target, located in the center of the camber, from top hemisphere, while the other half illuminates the target from the bottom hemisphere of the chamber. The chamber itself is an evacuated 10-meter diameter aluminum sphere located in a shielded target bay. The transition plan will proceed in four consecutive phases. facility during these phases. The modularity of the facility is fundamental to the transition plan, as it allows installation, acceptance testing and start-up in one laser bay, concurrent with limited experimental operation of one or more laser bundles in the other laser bay. This is particularly important during the initial start-up of the first bundle and installation of laser bay special equipment. Figure 2 shows schematically the status of the facility during these phases. The modularity of the facility is fundamental to the transition plan, as it allows installation, acceptance testing and start-up in one laser bay, concurrent with limited experimental operation of one or more laser bundles in the other laser bay. This is particularly important during the initial start-up of the first bundle and installation of the laser bay special equipment.

## II. NIF START-UP

NIF Start-up is defined as the performance testing that follows installation and off-line acceptance testing of subsystems, structures and components in the facility. The initial laser performance requirements for NIF during start-up are based on the NIF Functional Requirements and Primary Criteria, taking into account the limited operational experience and optics conditioning requirements. These requirements have been flown down into acceptance criteria for individual operational test procedures to be conducted during the start-up phase of the NIF laser.

Start-up testing is performed on individual bundles. It consists of a set of 16 individual test procedures, which are completed in three distinct phases. During the first phase, the main laser will be operationally tested within the laser bay. This includes activation and integration of all main laser components, the laser alignment and diagnostic systems, and associated integrated computer controls. Once reproducible and reliable operation has been confirmed, a precision diagnostic system will be used to validate laser performance of individual beam lines under high intensity and long pulse conditions both at the fundamental wavelength (1 micron) and after frequency tripling in the equivalent target plane (0.35 micron). During the third phase, beam transport to the target chamber and final optics for both beam quads of each bundle will be tested. A final set of laser performance verification tests will then be conducted. These tests include the use of diagnostic targets and X-ray imaging diagnostics to verify beam pointing, synchronization and spot size at target chamber center, followed by test of power balance controls and beam smoothing systems. A start-test plan has been developed for the first NIF bundle, which describes in detail the individual steps and acceptance criteria for each of the 16 operational test procedures that constitute the start-up of an individual bundle. Figure 3 shows a diagram of the 16 operational test procedures defined for the start-up of the first bundle.

The timetable for start-up of each bundle is shown in Fig. 4. The schedule for Program experiments following each bundle start-up is also shown. In the following sections we discuss in more detail the role of the first bundle in facilitating the start-up of the remainder 23 bundles, and the interaction of start-up and early experimental capability in the F02-FY04 time period.

## III. START-UP AND OPERATION OF THE FIRST NIF BUNDLE

NIF employs the concept of an early bundle operation, which serves several important purposes. First, it provides the first feedback regarding the integration of NIF sub-systems into a working beam line. Second, it allows training of operations personnel and validation of procedures so that subsequent bundle-by-bundle start-up at the rate of one per month is possible. Third, it provides early ICF experimental capability for NIF users.

The early bundle also requires early start-up of the Line Replacement Unit (LRU)

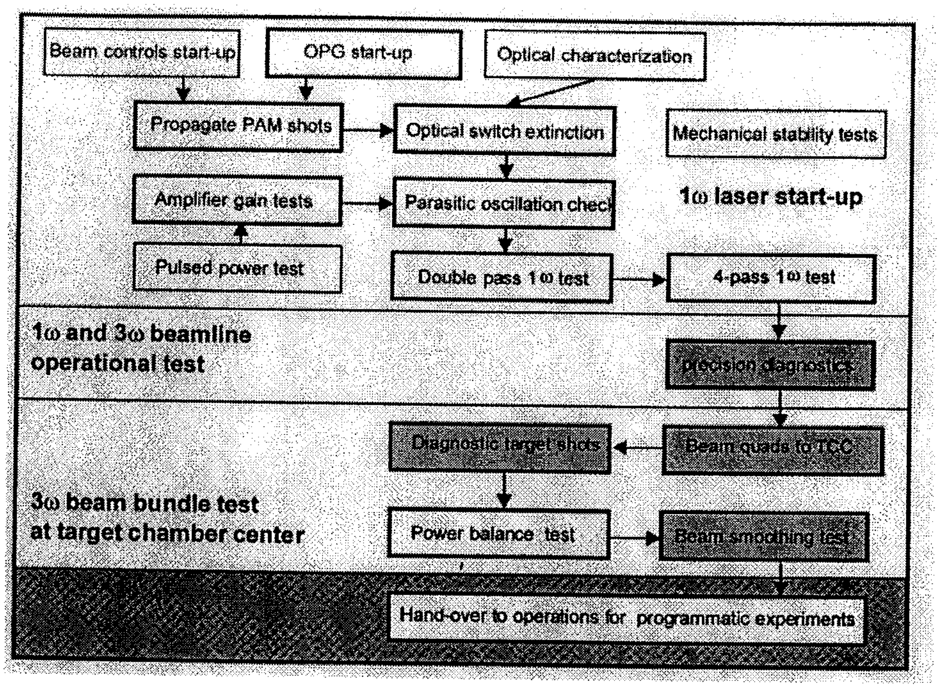


Figure 3.

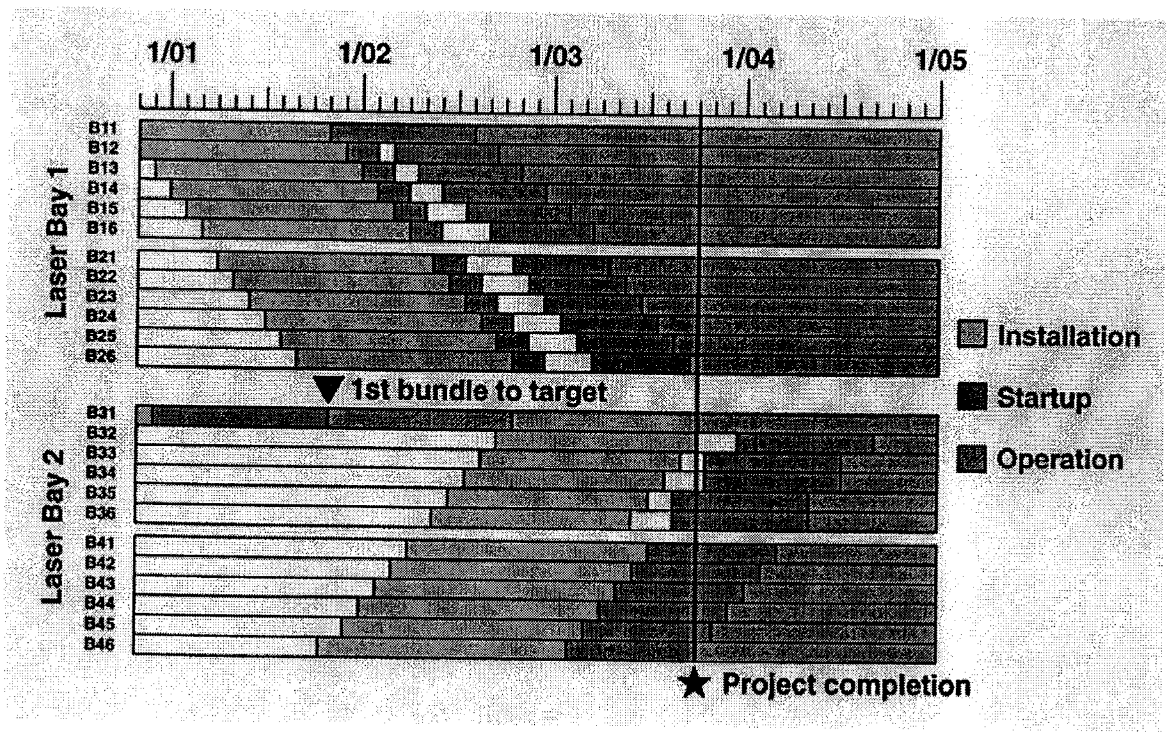


Figure 4.

assembly process. This process is a complex chain of activities that include receiving inspections, storage, precision cleaning, optics processing, LRU assembly, alignment and verification prior to installation in the beam line structures. During the final installation over 130 LRU's need to be completed per month. The first bundle provides the opportunity for a pilot run of this process, and allows a period of several months to optimize process steps and procedures.

In order to achieve first bundle operation as early as possible and increase the time between bundle 1 and laser bay 2 bundle deployment, it was decided that optical assemblies for the first bundle would be installed in Laser Bay 2 before final temperature stability is reached in the facility. Installation of hardware begins as soon as the laser bay is cleaned by Conventional Facilities, and optics assemblies are installed when temperature fluctuations are approx. +/-5 °C. Final temperature control requirements are +/- 0.5 °C. The increased alignment tolerances of the optical components will result in a slightly smaller clear aperture for the first bundle, estimated at 5%. In the worst case, this might lead to a 10% reduction in energy and power available for 1st bundle experiments.

The early experimental tests on the first bundle, concurrent with facility construction and start-up, provide a synergetic environment, where the driver performance and target chamber support systems can be tested and optimized for the remainder bundles by the laser engineering and scientific staff. This insures the smooth transition to a fully operational facility and reduces the time required to perform critical experiments requiring full system capability. The first bundle provides the opportunity to maintain the scientific and engineering expertise in an operational facility with capability and complexity similar to the size of existing facilities such as Nova facility at LLNL and the OMEGA Upgrade at LLE, University of Rochester. The expertise required to run a facility the size of NIF will therefore be able to grow with the increasing capabilities, as new bundles become available one at a time during completion of the start-up.

## IV. START-UP OF REMAINING 23 BUNDLES

After the first bundle (Bundle 31 in Laser Bay 2) has been operational for nearly one year, start-up of the first bundle of Cluster 1 in Laser Bay 1 will have been completed and the bundle will then be handed over to NIF operations. From that time on, one bundle will become available every month for user experiments until the completion of the Project, defined by completion of Laser Bay 1 start-up test procedures. The start-up of the laser bundles in laser bay 1 will be performed following a plan similar to the first bundle. We expect that the first bundle will have validated off-line verification techniques that simplify the on-line tests. As more and more bundles become available, the added laser energy and power increases the experimental capability of the facility. The target diagnostic instrumentation implemented during the first bundle operation will be expanded to make efficient use of the facility.

Until Project completion, there will be many challenges in orchestration of concurrent Conventional Facilities, equipment installation, and start-up activities in one facility. The Project has been structured to allow the first bundle to operate as long as possible by installing the other 3 clusters of laser hardware before installing hardware in the same cluster as the first bundle. As shown in Fig. 4, the first bundle is forced to cease operation by the need to install adjacent hardware. Since the definition of the Project completion requires just that Laser Bay 2 hardware be installed, plans for realignment, refurbishment and restart of the first bundle are not yet worked out. The target area is also affected by overlapping activities, since it is both latest in time for Conventional Facilities, and beam quads have a 3-D aspect not present in the laser bays. We are currently assuming one shift operation per day for shot operations.

During the construction phase of the Project, there will be constant real-time changes in laser equipment installation plans, which will be affecting downstream activities in complex ways. An information system will be implemented to issue work orders and track over 20000 assembly, installation, acceptance and operational test activities during the 3 years required to complete laser installation. This information system is also linked to databases that manage parts inventory and contain optical component metrology data, as well as results of individual acceptance and operational tests, including shot archival data.

By the end of the NIF Construction project half of the 24 laser bundles will have been qualified and handed over to the NIF operations organization, while all special equipment will have been installed and acceptance tested, ready for start-up testing during FY04. At that time a fully developed operations organization will be in place with a significant amount of operational experience. The start-up of the remainding 12 laser bundles in the second laser bay will proceed more rapidly than the laser bay 1 bundles (shown in Fig. 4). Simultaneous operation of all 24 bundles is expected to be reached by the end of FY04, at which time the full energy of 1.8 MJ will be available in the Indirect drive configuration.

## V. ICF PROGRAM EXPERIMENTS DURING THE PROJECT COMPLETION OF START-UP (FY02-03)

After completion of the 1st bundle start-up activities, this bundle will become available for target experiments throughout FY02. Prior to operation, the Project will complete an Operational Readiness review. Cluster 1 and 2 will subsequently become available for operation at the rate of one bundle per month starting at the end of FY02 up to the end of the Project in FY03. The remaining 12 bundles of cluster 3 and 4 will become available to operations through FY04. At the hand-over to operations, the bundles will nominally operate at an energy of 5 kJ per beamline at 3ω. The energy output will be ramped up to the nominal 75 kJ output per bundle over a sequence of shots commensurate with optics conditioning requirements and operational experience. This minimizes risks for early damage to optical components. The estimated total 3ω energy ramp-up rate corresponding to the bundle-by-bundle start-up is shown in figure 5.

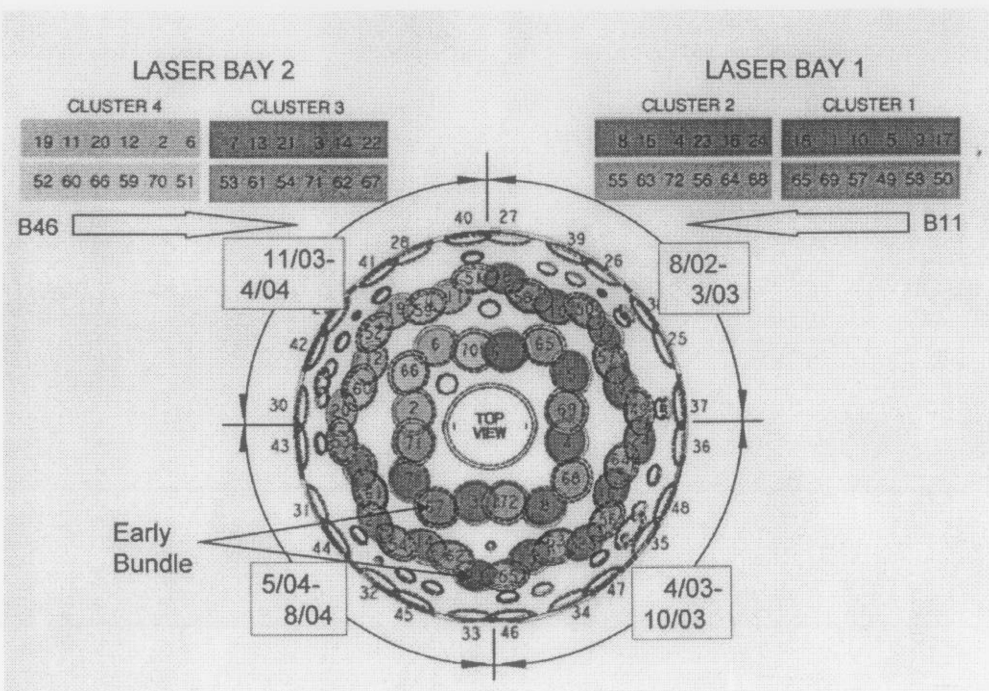


**Figure 5.**

The Project's need for efficiency in laser equipment installation, correlated to position in the laser bay, results in a non-symmetric target irradiation pattern during start-up. Figure 6 shows how each of the clusters is mapped onto one quadrant of the target chamber sphere. At the end of FY03, the beams available cover one hemisphere, and the illumination mode of targets remains asymmetric until all bundles become available. This illumination asymmetry limits the expected yield from ignition experiments; but does not prevent a large array of experiments required to establish proper conditions of ignition or obtain important high energy density and weapons physics data. The system can also be used extensively to test and optimize new diagnostics as they become available.

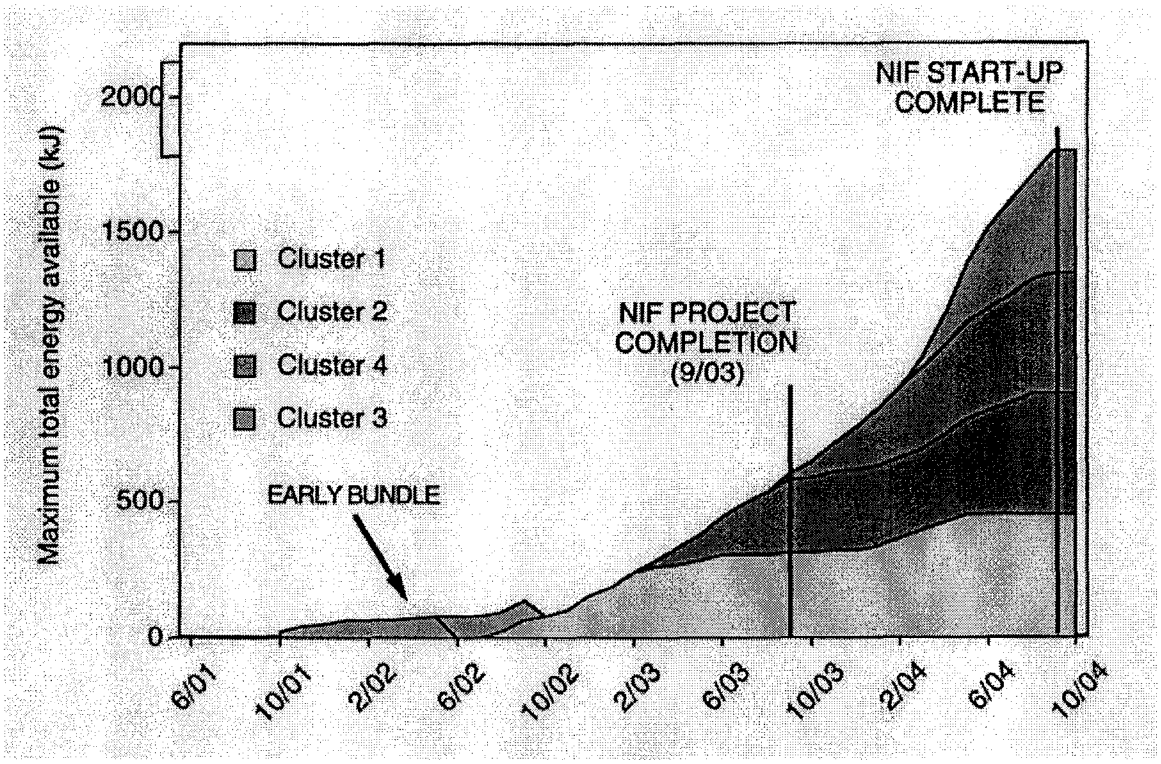


**Figure 6.**

The number of target shots available during initial operations is limited by the concurrent installation and start-up during the project, and the concurrent completion of start-up during FY04. During the Project one shift per day will be available for shot operations, except for a small period of time near the end of FY03, when equipment installation in the first laser bay has been completed. During most of FY04, two shifts of shot operations will be available. A plan has been compiled for the total number of target shots available, based on the assumption that each bundle can be fired once per 8 hr shot shift. This plan estimates the number of shots using all available bundles to be 400 by the end of the Project, and 884 by the end of FY04. When using subsets of bundles for target shots, more shots are available. The total number of target shots per shift is limited to three shots, based upon operational and start-up considerations.

It is realistic to assume that some level of refurbishment of optical assemblies in operational bundles will be required by the Operating Program during initial operation. During the installation of LRU's, the NIF Optics Assembly area operates at nearly full capacity, with limited room for maintenance and refurbishment. As the number of operating bundles and the shot rate increases during the last half of FY03, the increased refurbishment requirements nearly coincide with the drop in initial LRU installation activity. The detailed requirements for debris shield processing, and the availability of phase plates as required for target experimental campaigns are presently being analysed by the Operating Program.

## VI. SUMMARY

## VII. ACKNOWLEDGEMENTS

This work has been completed by LLNL for the U.S. Department of Energy under Contract number W-7405-Eng-48.

## VII REFERENCES


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## [LIST OF FIGURE CAPTIONS]

Fig. 1. Isometric layout of the NIF facility design (Title I status), showing the two laser bays, two switchyards with the central target bay housing the 10 m diameter evacuated target chamber. Each laser bay is surrounded by two bays, which house the capacitor banks to drive the flash lamp pumped laser amplifiers. A clean room area for LRU assembly and maintenance is located next to the laser bays.

Fig. 2. Schematic representation of the 4 phases of the transition plan to a fully operating NIF facility with early experimental capability concurrent with installation and start-up.

Fig. 3. The start-up plan for individual bundle consists of 16 operational test procedures divided in three consecutive phases.

Fig. 4. Time schedule for installation, start-up and hand-over to NIF operations for each of the 24 NIF bundles. The first bundle is Bundle 31, located in the second laser bay, next to the central operations area. Subsequent bundles will be activated starting in Laser Bay 1, followed by Laser Bay 2, each time going from the outside bundle to the central area.

Fig. 5. Time schedule of the target irradiation symmetry resulting from the start-up sequence shown in figure 3. Full symmetry will not be available until completion of the start-up activities in Laser Bay 2 (the end of FY04).

Fig. 6. Maximum energy available from the NIF laser in the Indirect Drive configuration as a function of time during the initial operations period, concurrent with equipment installation and start-up. The gray scales indicate the energy ramp-up of the four individual clusters of 6 laser bundles each.